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Possibility of Saturnian Synchrotron Radiation

by

Joe L. Luthey

Department of Physics and Astronomy
University of Iowa
Iowa City, Iowa 52240

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LIST OF SYMBOLS

$°K$	degrees Kelvin
R_S	1 Saturn radius (upper case subscript)
AU	Astronomical Unit
S	Flux density
a, b	dummy variables (lower case)
λ	wavelength (lower case Greek letter lambda)
λ_c	critical wavelength (lower case subscript)
λ_m	wavelength of synchrotron spectral maximum (lower case subscript)
μ	micron (lower case Greek letter mu)
mf.u.	abbreviation for milli-flux unit
α	electron pitch angle (lower case Greek letter alpha)
$\alpha*$	angle between line of sight of the observer and magnetic field line
B	Magnetic field intensity
B_o	surface magnetic field intensity at the equator (lower case subscript naught)
ν	frequency (lower case Greek letter nu)
ν_c	critical frequency (lower case subscript)
ν_m	frequency of synchrotron spectral maximum (lower case subscript)
P	power
E	energy

e	electron charge
m	electron mass
c	speed of light
F,f,g,h,j	function symbols
β	magnetic field loading factor (lower case Greek letter beta)
y	dummy variable (lower case)
x	dimensionless argument of the above five functions (lower case)
x_m	dimensionless argument of the maximum of F (lower case and lower case subscript)
$K_{5/3}$	modified Bessel function of the second kind. 5/3 is a subscript
π	mathematical constant (lower case Greek letter pi)
N	number of electrons
V	emission volume
n	electron number density
R	distance from observer to Saturn
C	dummy constant (capital letter)

Abstract

Several synchrotron spectra are computed for a hypothetical Saturnian radiation belt. A monoenergetic distribution of relativistic electrons is assumed to exist in a toroidal volume in a dipole magnetic field aligned with the rotation axis. When synchrotron emission is added to the thermal component implied by observations at wavelengths shorter than 50 cm, the upturn in the total emission spectrum can become gradual to quite sharp depending on the critical wavelength and the number density of radiating electrons. The amount of nonthermal emission is estimated to be 14.6 mf.u. at 73.5 cm; and with the constraint of the pressure balance equation, the ranges of magnetic field intensity, and electron energy and density are tabulated and nomographically illustrated. The present observations are insufficient to determine the critical wavelength; but for several estimates of the magnetic field loading factor, the minimum surface magnetic field intensity and minimum electron number density are computed.

INTRODUCTION

Over the past decade radio observations of Saturn at decimetric wavelengths have yielded fluxes which exceed those expected from the planetary disc at a temperature of 95 °K (Low, 1966). The departure in intensity from the 95 °K blackbody curve increases monotonically with increasing wavelength. A similar feature in Jupiter's spectrum led to the discovery of the nonthermal component due to synchrotron emission and to the establishment of the existence of the Jovian radiation belt. Available observations of Saturn do not clearly establish a nonthermal component of the radiation, nor has an extended radio source beyond the planetary disc been detected. However, observations at 73.5 cm by McAdam (1971) and more recently at 49.5 cm by Yerbury *et al.* (1971) do admit the possibility of a synchrotron source if the thermal component implied by shorter wavelength observations is subtracted from the total intensity at these two wavelengths. Observations in the decametric range have not conclusively revealed a Jovian-type burst phenomenon (Smith and Carr, 1959; Carr *et al.*, 1961).

Observations of the Saturnian decimetric emission are listed in Table I and a graph of the radio observations in Table I is shown in Fig. 1. For shorter wavelengths see the list in Gulkis et al. (1969). The effective blackbody temperatures have been converted to flux densities by the Rayleigh-Jeans law and by assuming the emission comes from a disc having the angular size of Saturn at 8.0 AU, i.e., subtending a solid angle of 7.5×10^{-9} steradians. The adopted distance is the minimum separation between the orbit of Saturn and a heliocentric circle of radius 1 AU in the ecliptic plane. The heavy, straight line is the blackbody spectrum for a 95 ± 3 °K disc temperature based on infrared observations (Low, 1966) at 20 microns wavelength. From 1.53 cm to 49.5 cm wavelength, the observed intensities exceed the blackbody emission, and this departure increases monotonically with increasing wavelength.

A least squares fit of the form $\log S = a \log \lambda + b$ was made to the data in Fig. 1 from 1.53 cm to 49.5 cm. For the flux density S in milli-flux units* (mf.u.) and wavelength λ in centimeters, the fitted curve is

$$\log S = -1.761 \log \lambda + 4.384 \quad . \qquad (1)$$

Beyond 50 cm wavelength, there is a barely significant indication of an upward departure from curve (1). Gulkis et al. (1969) have interpreted the non-blackbody curve (1) as the emission from a deep hot atmosphere characterized by an adiabatic temperature

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*1 milli-flux unit = 10^{-29} watts m^{-2} Hz^{-1}

gradient. Such an atmosphere with ammonia as the only absorber in a hydrogen-helium mixture gives excellent agreement with the observations and predicts a sharp increase in the disc temperature somewhere beyond 50 cm wavelength, depending on the abundance ratio of ammonia.

NONTHERMAL EMISSION FROM A SATURNIAN RADIATION BELT

Despite the appeal of the atmospheric model of Gulkis *et al.* and the possibility that it may provide an adequate explanation of the radio spectrum of Saturn, it is of interest to consider the possibility of nonthermal emission from energetic electrons in a Saturnian radiation belt. Existing observational data are adopted as a constraint.

The particulate rings of the planet extend to nearly 2.5 planetary radii (R_S) in the equatorial plane. Hence it is reasonably certain that a durable radiation belt can not exist inside of 2.5 R_S, unless the magnetic field is grossly distorted in some such manner as suggested by Zheleznyakov (1965). In what follows, it is assumed that such distortion does not exist. Cyclotron emission is rejected as a nonthermal source because magnetic field intensities of several hundred gauss would be required in the emission region in order that the first several harmonics of the cyclotron frequency fall into the observed frequency range. Such field intensities are thought to be unreasonably great when compared to those of the Earth and Jupiter, the only other planets known to be magnetized.

Therefore, only the synchrotron process is considered. For the purpose of this investigation, a monoenergetic isotropic distribution of relativistic electrons is assumed to exist in the magnetic field of a centered dipole whose axis is parallel to the axis of rotation of the planet. The populated volume is taken to be an equatorial toroid having ten times the volume of the planet, a mean radius of 3 R_S, and an axial thickness of 1 R_S. The magnetic field intensity is assumed uniform and equal to its equatorial value at 3 R_S throughout the toroid.

For a single electron of mass m and charge e spiraling with pitch angle α in a magnetic field B, the total emitted spectral power at frequency ν, integrated over all angles, is

$$P(\nu,E,B) = \frac{\sqrt{3}\, e^3\, B}{mc^2} \sin\alpha \; F(\nu/\nu_c) \tag{2}$$

where

$$F(x) = x \int_x^\infty K_{5/3}(y)\, dy \tag{3}$$

$$x = \frac{\nu}{\nu_c} = \frac{\lambda_c}{\lambda} \tag{4}$$

and the critical frequency for an electron of total energy E is

$$\nu_c = \frac{3}{4\pi} \frac{eB}{mc} \left(\frac{E}{mc^2}\right)^2 \sin\alpha \quad . \tag{5}$$

The notation for the integral F(x) is the same as Legg and Westfold's (1968) where $K_{5/3}$ is a modified Bessel function of the second kind. The maximum of F(x) for the frequency ν_m at maximum occurs at

$$x_m = \frac{\nu_m}{\nu_c} = \frac{\lambda_c}{\lambda_m} = 0.29 \tag{6}$$

The emission cone of such a relativistic electron is sharply peaked in the direction of motion so that an observer whose line of sight makes an angle α^* with the magnetic field line receives radiation primarily from those electrons that have pitch angles near α^*. For relativistic electrons then, the integration over pitch angle is approximately equal to the integration over all space angles divided by the normalization constant of the pitch angle distribution. For an isotropic pitch angle distribution, the intensity in milli-flux units received at distance R from N electrons of the same energy is approximately

$$S = N \frac{\sqrt{3}\, e^3 B}{mc^2} \frac{10^{26}}{4\pi R^2} \sin \alpha^* F(x) = N\, B\, F(x)\, C \qquad (7)$$

For simplicity in the calculations which follow and to obtain maximum emission, the angle α^* was set equal to $\pi/2$.

The synchrotron spectrum of a monoenergetic distribution of electrons is characterized by the value of the critical wavelength λ_c. By increasing or decreasing λ_c, the peak of the synchrotron spectrum can be shifted to longer or shorter wavelengths, respectively. By increasing or decreasing the quantity NB in Equation (7), the spectrum can be moved up or down. It should be possible then to determine λ_c by varying NB and λ_c until the computed synchrotron plus thermal spectrum closely approximates the observations. However, existing observations apparently do not extend far enough to the longer wavelengths to enable this determination of λ_c.

To illustrate the diversity of shape of the computed total emission spectrum, spectra having λ_c = 8.1 cm, 81 cm, and 400 cm are shown in Figs. 2, 3, and 4, respectively. The synchrotron spectrum of Equation (7) was shifted in wavelength and added to the thermal emission curve of Equation (1). The computed spectra were adjusted in intensity so as to pass through the most probable value of the intensity at 73.5 cm wavelength. About 14.6 mf.u. are attributed to the nonthermal component at 73.5 cm after subtraction of the thermal component given by Equation (1).

There may very well continue to be an ambiguity of interpretation because the mixing ratio of ammonia in the Saturnian atmosphere and other parameters in the Gulkis model can be adjusted to yield results similar to those in Figs. 2 and 3. However, as illustrated by Fig. 4 (λ_c = 400 cm), some synchrotron spectra yield sharply increasing values of S for λ > 100 cm; and such increases are beyond the capability of the deep hot atmosphere model.

Otherwise, synchrotron emission is potentially distinguishable from thermal emission on two grounds. First, it constitutes an extended source, far beyond the disc of the planet; second, it exhibits linear polarization.

ESTIMATIONS OF THE MAGNETIC FIELD INTENSITY, ELECTRON ENERGY, AND NUMBER DENSITY

Although further radio observations beyond 73.5 cm may eventually suggest a value of λ_c, the number of electrons N, the energy E, and the magnetic field intensity B_o at the equatorial surface of Saturn still cannot be determined unambiguously. For the synchrotron model used here, any combination of B and E that gives a particular value of ν_c (or of the critical wavelength λ_c) in Equation (5) will suffice; and the number of electrons N is then chosen so that the sum of the synchrotron and thermal contributions passes through all the observed intensities. However, using the constraint of the pressure balance equation, this ambiguity can be limited to the uncertainty in one or two variables which can be estimated or eventually measured. The form of the pressure balance equation is

$$nE = \beta\, B^2 / 8\pi \tag{8}$$

where $n = N/V$ is the number density of the electrons with total energy E in the emission V of the toroid; and β is the ratio of the relativistic electron energy density to magnetic field energy density. The number of electrons N can be eliminated by substitution of Equation (7) for N with $\alpha^* = \pi/2$ and $R = 8.0$ AU. For S in milli-flux units, E in MeV, B in gauss, the wavelength λ in centimeters and a radiation volume V ten times the volume of Saturn, Equation (8) becomes

$$f(x) = \beta\, F(x) \tag{9}$$

where

$$f(x) = 3.64 \times 10^{-11}\ SEB^{-3} \quad . \tag{10}$$

If E above is substituted by its relation to ν_c in Equation (5), and if ν_c, in turn, is substituted by its relation to x and λ in Equation (4), the solution for the magnetic field intensity may be expressed

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as a function of x, and as a function of measured and estimable quantities,

$$g(x) = S^{-1} \lambda^{1/2} \beta F(x) \tag{11a}$$

$$g(x) = 1.57 \times 10^{-9} x^{-1/2} B^{-7/2} . \tag{11b}$$

It is assumed that the nonthermal component S can be isolated from the total emission by subtraction of the thermal component. Thus S and the wavelength λ of observation constitute the measured quantities in Equation (11a). The quantity β is unknown and unlikely to be determined except by a direct measurement; however, it can be estimated from known or predicted relativistic electron densities in the magnetospheres of the Earth and Jupiter. The independent variable x is ultimately a measureable quantity and depends on the shape and wavelength position of the total emission spectrum. However, existing observations do not permit a determination of λ_c and therefore x is presently unknown.

The solution for the energy E may be similarly expressed as a function of x, and as a function of measured and estimable quantities by a substitution for B in Equation (10) using Equations (5) and (4). The function is

$$h(x) = S^{-1} \lambda^{-3} \beta F(x) \tag{12a}$$

$$h(x) = 5.67 \times 10^{-21}\ x^3\ E^7 \quad . \tag{12b}$$

Corresponding to each combination of B and E at x for each estimate of β, there is a number density n that gives the observed nonthermal intensity at wavelength λ. A substitution of Equations (11a, b) for B in Equation (7) gives a function j(x) similar to the functions g(x) and h(x) for the solution of the number density n,

$$j(x) = S^{5/2}\ \lambda^{1/2}\ \beta\ F(x) \tag{13a}$$

$$j(x) = 2.07 \times 10^{12}\ x^{-1/2}\ [n \cdot F(x)]^{7/2} \quad . \tag{13b}$$

The functions g(x), h(x), and j(x) are plotted logarithmically in Fig. 5 for several different values of constant B_o, E, and n, respectively. B_o is the surface magnetic field intensity at the equator. If the Saturnian spectrum is known well enough to determine the value of x at a wavelength λ of observation, the value of F(x) can be taken either from the logarithmic plot of this function in Fig. 6 or interpolated from a table of F(x) given by Legg and Westfold (1968). Then with the nonthermal flux S determined by the observation and with an estimate of β, the quantities B_o, E, and n can be determined by Equations (11a) through (13b).

Since existing observations are insufficient to give λ_c, the quantities B_o, E, and n can only be determined for a range of x for each estimate of β. However, for each β a lower limit on B_o

and n can be obtained even though x is unknown. Comparing Fig. 5 with Fig. 6, it is evident that a line of $g(x)$ for a constant B_o is tangent to the curve $F(x)$, which, on a logarithmic scale, is raised or lowered by the factor $(S^{-1} \lambda^{1/2} \beta)$. The point of tangency occurs at $x = 0.81$ for which $F(0.81) = 0.73783$. All lines of $g(x)$ for constant B_o that lie above the point of tangency are excluded by the pressure balance equation. All values of B_o larger than the minimum correspond to parallel lines of $g(x)$ that pass below the point of tangency and intersect the curve $(S^{-1} \lambda^{1/2} \beta) \cdot F(x)$ at two points.

The minimum number density occurs where the curve of $j(x)$ for constant n touches the curve $F(x)$, which, on a logarithmic scale, is raised or lowered by the factor $(S^{5/2} \lambda^{1/2} \beta)$. The abscissa of the minimum is $x = 0.091$ for which $F(0.091) = 0.80328$. All curves of $j(x)$ for constant n that lie below the point of tangency are excluded by the pressure balance equation; and each value of n that is larger than the minimum corresponds to a curve of $j(x)$ for constant n that intersects the curve $(S^{5/2} \lambda^{1/2} \beta) \cdot F(x)$ at two points.

NUMERICAL EXAMPLES

The only observation that suggests the possibility of non-thermal emission is the observation at 73.5 cm. After subtraction of the thermal component given by Equation (1), the resultant nonthermal component is 14.6 mf.u. The estimates of β in the Saturnian magnetosphere are made consistent with similar values in the jovian and terrestrial magnetospheres. For example, the value of β for relativistic electrons of energy $E > 1.6$ Mev in the Earth's outer zone varies from about 10^{-4} to 10^{-6} [see e.g. Frank et al. (1964)]. Estimates of β for relativistic electrons in Jupiter's radiation belt range from 10^{-5} to 10^{-9} [Beard and Luthey (1972), Warwick (1970), and others]. For a range of β from 10^{-5} to 10^{-7}, the radiation belt parameters B_o, E, and n are computed for each decade of x from 0.001 to 10, and the results are listed in Table II. Also included in the table are the radiation belt parameters for the two abscissae corresponding to a minimum B_o ($x = 0.81$) and a minimum n ($x = 0.091$).

The 14.6 mf.u. of nonthermal emission corresponds to the most probable value of the 73.5 cm observation. The nonthermal flux corresponding to the lower error bound of this observation is only 4.2 mf.u., and the amount corresponding to the upper error bound is 25.1 mf.u. Since the thermal component at 73.5 is such a large part of the total emission, the estimates of the Saturnian radiation belt parameters in Table II are quite sensitive to any changes in the thermal component and especially to the lower error limit of the observation. By Equations (11a, b) and (12a, b), the magnetic field intensity and the energy are least affected by lower estimates of the nonthermal flux since $B_o \sim S^{2/7}$ and $E \sim S^{1/7}$; and the number density is most affected by lower estimates of S since $n \sim S^{5/7}$ [from Equations (13a, b)]. As an example, consider the change in the minimum B_o and n for $\beta = 10^{-5}$ if, instead of 14.6 mf.u. of nonthermal emission, S = 1.46 mf.u., a reduction of the nonthermal component by an order of magnitude. Then the minimum B_o is $2.8 \cdot (0.1)^{2/7} = 1.5$ gauss, and the minimum number density is $1.2 \times 10^{-4} (0.1)^{5/7} = 2.3 \times 10^{-5}$ electrons cm^{-3}.

A graphic illustration of the relations among g(x), h(x), j(x), and $\beta F(x)$ is shown in Fig. 7 for the specific example of S = 14.6 mf.u. at 73.5 cm. The ordinate is f(x) of Equation (9) which is common to all the other functions; viz. g(x), h(x), and j(x). The figure is also a nomogram for B_o, E, and n. Given the value of x, which can be determined by the wavelength of observation and the value of λ_c most closely approximating the spectrum, and a reasonable estimate of β, the values of B_o, E, and n can be read off or interpolated at the intersection of two lines: one through f(x) and parallel to the abscissa, and the other line through x and parallel to the ordinate. A more accurate determination of the radiation belt parameters should be made from Equations (11a) through (13b).

SUMMARY AND DISCUSSION

With the hypothesis of a Saturnian radiation belt, a wide range of estimates of the radiation belt parameters (magnetic field intensity, electron energy and number density) has been computed under the constraint of existing observations and the pressure balance equations. Many of these estimates are comparable to similar estimates for the jovian magnetosphere. For the observation at 73.5 cm with 14.6 mf.u. attributed to synchrotron emission, a nomogram has been constructed for a visual determination of radiation belt parameters. Whenever a nonthermal component can be isolated, such a nomogram may be easily constructed using the appropriate figures and equations in the text.

The sample spectra of the total emission indicate the diversity of shapes of the possible synchrotron plus thermal sources. Hopefully observations at meter wavelengths, if they indicate a nonthermal source, can limit the range of the critical wavelength λ_c. With the present uncertainty in λ_c, only minimum values of B_o and n can be computed for estimates of the magnetic field loading factor.

It is reasonably certain that the Saturnian ring system precludes the formation of any large intense radiation belt below 2.5 R_s. This is consistent with the fact that decimetric observations of Saturn have not revealed a nonthermal source at wavelengths shorter than 50 cm. Since the strength of the assumed dipole magnetic field is much weaker at 3 R_s than at the equatorial surface, falling off as the inverse cube of the distance from the center of the planet, any possible synchrotron emission is understandably feeble. Yet if a nonthermal source should be detected at meter wavelengths, the magnitude of the surface magnetic field intensity B_o at the equator (see Table II) suggests that the Saturnian magnetosphere should then contain appreciable fluxes of high energy electrons (and protons) at and beyond 3 R_s.

In closing, it should be noted that for meter wavelength observations, a nonthermal source may be difficult to differentiate from a thermal source if the emission from the deeper layers of the Saturnian atmosphere exceeds the amount given by the spectrum implied by observations at wavelengths shorter than 50 cm. The two emission mechanisms will both contribute to any measurement of the total power.

Table I

Observed Decimetric Spectrum of Saturn

Wavelength (cm)	Temperature (°K)	References	
1.18	130.8 ± 5.0	Wrixon and Welch	(1970)
1.26	127.2 ± 5.5	Wrixon and Welch	(1970)
1.46	133.2 ± 7.5	Wrixon and Welch	(1970)
1.53	139 ± 12	Wrixon and Welch	(1970)
1.53	146 ± 23	Welch and Thornton	(1965)
1.53	141 ± 15	Welch et al.	(1966)
1.90	140 ± 15	Kellermann and Pauliny-Toth [reported by Kellermann	(1970)]
3.12	137 ± 12	Berge	(1968)
3.45	144 ± 30	Cook et al. [reported by Seling	(1970)]
3.75	168 ± 11	Seling	(1970)
6.0	179 ± 19	Kellermann	(1966)
6.0	190 ± 45	Hughes	(1966)
6.0	176 ± 10	Pauliny-Toth [reported by Kellermann	(1970)]
9.0	165 ± 25	Berge and Read	(1968)
9.4	177 ± 30	Rose et al.	(1963)
10.0	196 ± 44 (m.e.)	Drake	(1962)
10.7	172 ± 20	Berge and Read	(1968)
11.13	163 ± 5*	Gerard	(1969)

*Average values obtained graphically.

Table I (continued)

Wavelength (cm)	Temperature (°K)	References	
11.3	196 ± 20	Kellermann	(1966)
11.3	182 ± 20	Davies et al.	(1964)
21.2	286 ± 37	Davies and Williams	(1966)
21.3	303 ± 50	Kellermann	(1966)
49.5	390 ± 65	Yerbury et al.	(1971)
70.0	< 1250	Gulkis et al.	(1969)
73.5	704 ± 273	McAdam [reported by Yerbury et al.]	

Table II

Estimates of B_o, E, and n for a Saturnian Radiation Belt for which S = 14.6 mf.u. at λ = 73.5 cm

(a) $\beta = 10^{-5}$

λ_c (cm)	x	B_o (gauss)	E (MeV)	n^+ (electrons cm^{-3})
0.0735	0.001	10.7	252	1.8 (-3)
0.735	0.01	6.2	105	1.3 (-4)
7.35	0.1	3.8	42.6	1.2 (-4)
73.5	1	2.9	15.4	1.9 (-4)
735	10	21.2	1.8	8.7 (-2)
6.7	0.091	3.9	44.1	1.2 (-4)
59.5	0.81	2.8	17.1	1.7 (-4)

+Numbers in parentheses are powers of 10.

(b) $\beta = 10^{-6}$

λ_c (cm)	x	B_o (gauss)	E (MeV)	n (electrons cm^{-3})
0.0735	0.001	20.7	182	9.1 (-4)
0.735	0.01	12.0	75.4	6.6 (-5)
7.35	0.1	7.3	30.7	6.0 (-5)
73.5	1	5.6	11.1	9.8 (-5)
735	10	40.9	1.3	4.5 (-2)
6.7	0.091	7.4	31.7	6.0 (-5)
59.5	0.81	5.5	12.3	8.7 (-5)

Table II (continued)

(c)

$\beta = 10^{-7}$

λ_c (cm)	x	B_o (gauss)	E (MeV)	n (electrons cm^{-3})
0.0735	0.001	40.0	131	4.7 (-4)
0.735	0.01	23.2	54.3	3.4 (-5)
7.35	0.1	14.1	22.1	3.1 (-5)
73.5	1	10.8	8.0	5.1 (-5)
735	10	79.0	0.9	2.3 (-2)
6.7	0.091	14.4	22.8	3.1 (-5)
59.5	0.81	10.6	8.8	4.5 (-5)

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FIGURE CAPTIONS

Figure 1. The decimetric spectrum of Saturn. The straight line through the data is a least squares fit of all observations in Table I with wavelength shorter than 50 cm [See Equation (1)].

Figure 2. Synchrotron spectrum for $\lambda_c = 8.1$ cm corresponding to $x = 0.11$ at 73.5 cm wavelength.

Figure 3. Synchrotron spectrum for $\lambda_c = 8.1$ cm corresponding to $x = 1.1$ at 73.5 cm wavelength.

Figure 4. Synchrotron spectrum for $\lambda_c = 400$ cm corresponding to $x = 5.5$ at 73.5 cm wavelength.

Figure 5. The functions $g(x)$, $h(x)$, and $j(x)$. Straight lines of negative slope are $g(x)$ for constant B_o, and straight lines of positive slope are $h(x)$ for constant E. Curved lines labeled n are $j(x)$ for constant n.

Figure 6. The function $F(x)$.

Figure 7. The function $f(x)$ for a nonthermal component of 14.6 mf.u. at 73.5 cm. Straight lines of positive slope are $f(x)$ for constant E, and lines of negative slope are $f(x)$ for constant B_o. Curved lines labeled n are $f(x)$ for constant n.

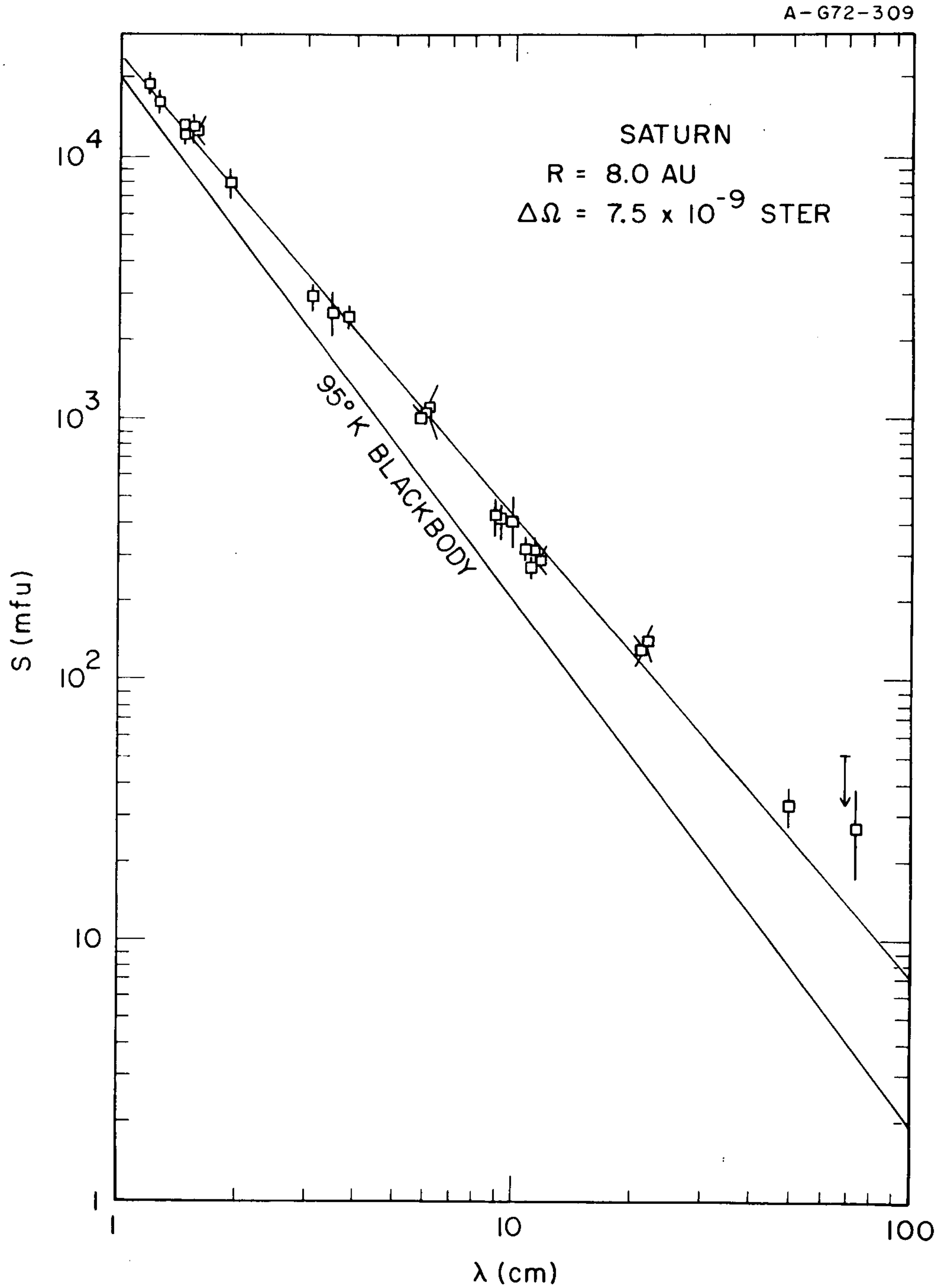

A-G72-309
SATURN
R = 8.0 AU
ΔΩ = 7.5 x 10^-9 STER
95° K BLACKBODY
S (mfu)
λ (cm)
10^4
10^3
10^2
10
1
1
10
100

Figure 1

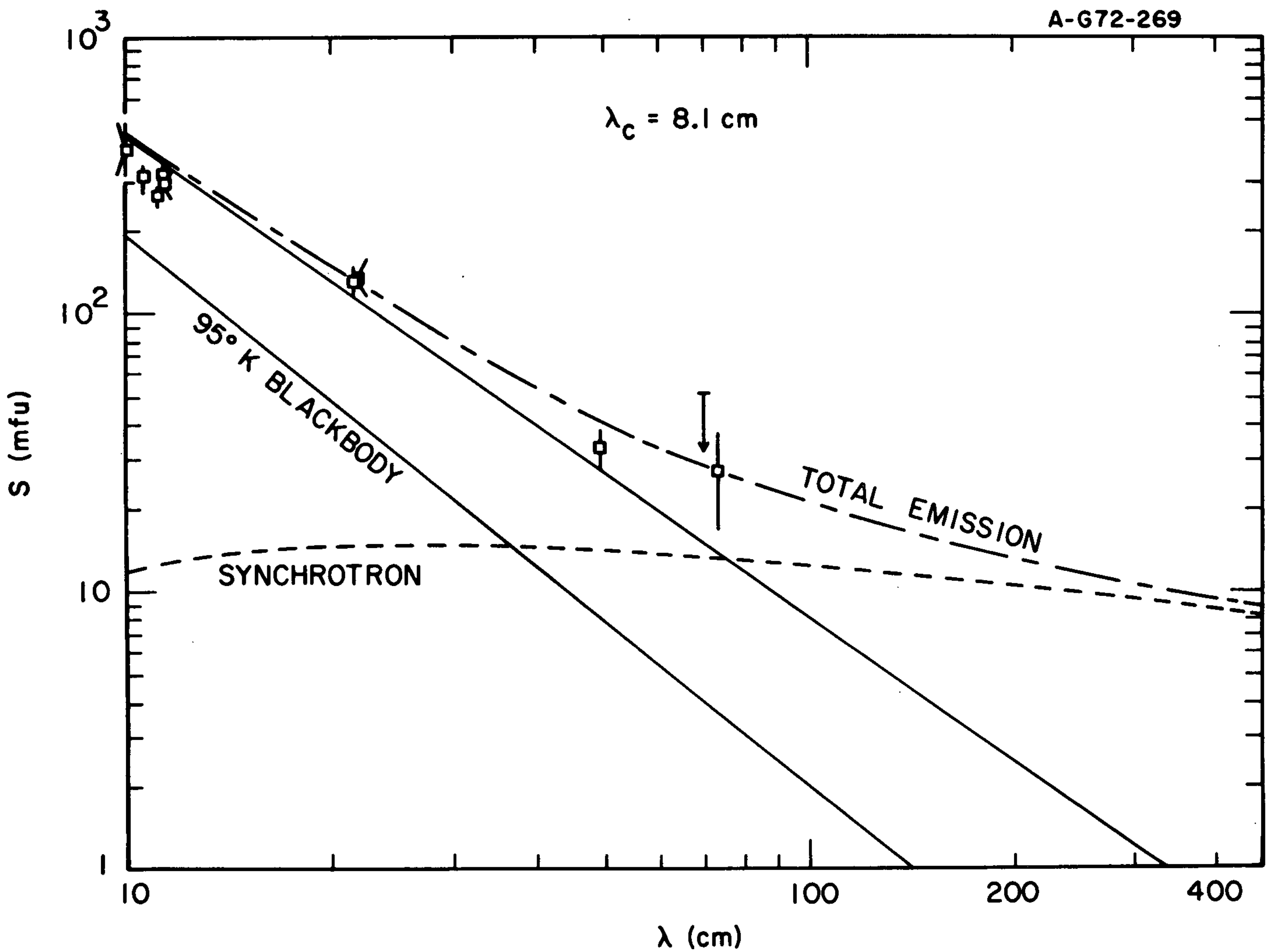

A-G72-269
λ_c = 8.1 cm
95° K BLACKBODY
TOTAL EMISSION
SYNCHROTRON
S (mfu)
λ (cm)
10^3
10^2
10
1
10
100
200
400

Figure 2

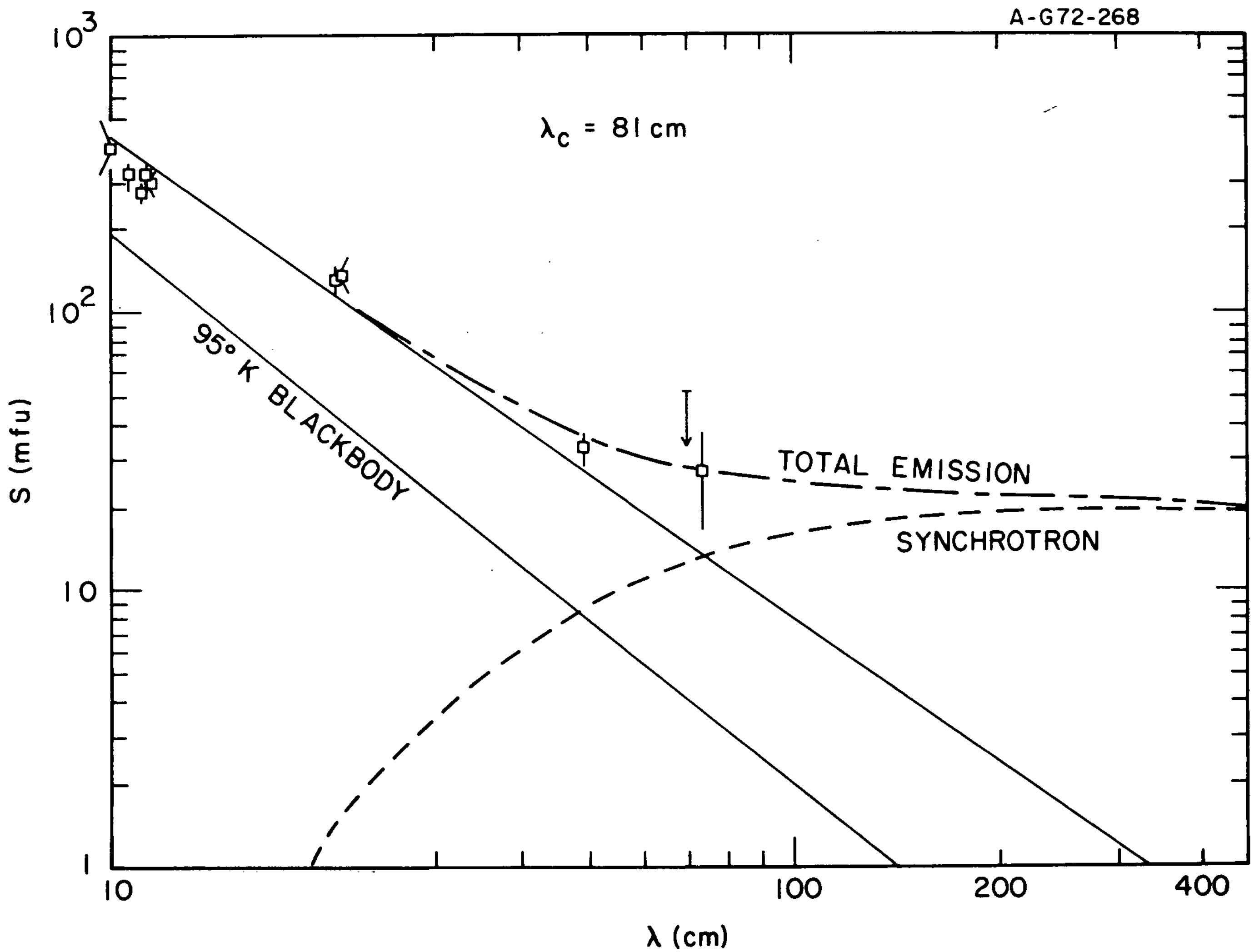

A-G72-268
λ_c = 81 cm
95° K BLACKBODY
TOTAL EMISSION
SYNCHROTRON
S (mfu)
λ (cm)
10^3
10^2
10
1
10
100
200
400

Figure 3

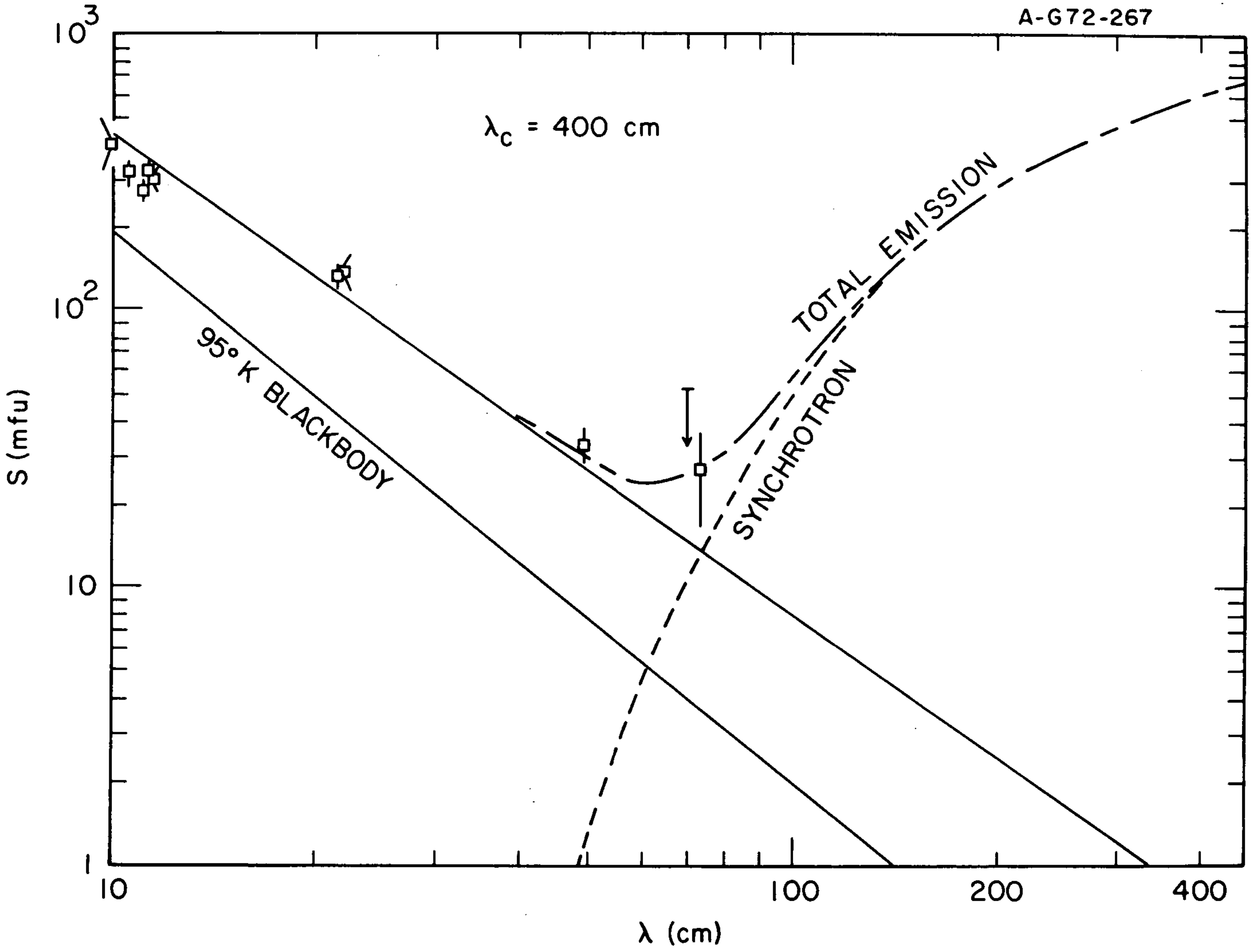

A-G72-267
λ_c = 400 cm
TOTAL EMISSION
SYNCHROTRON
95° K BLACKBODY
S (mfu)
10^3
10^2
10
1
10
100
200
400
λ (cm)

Figure 4

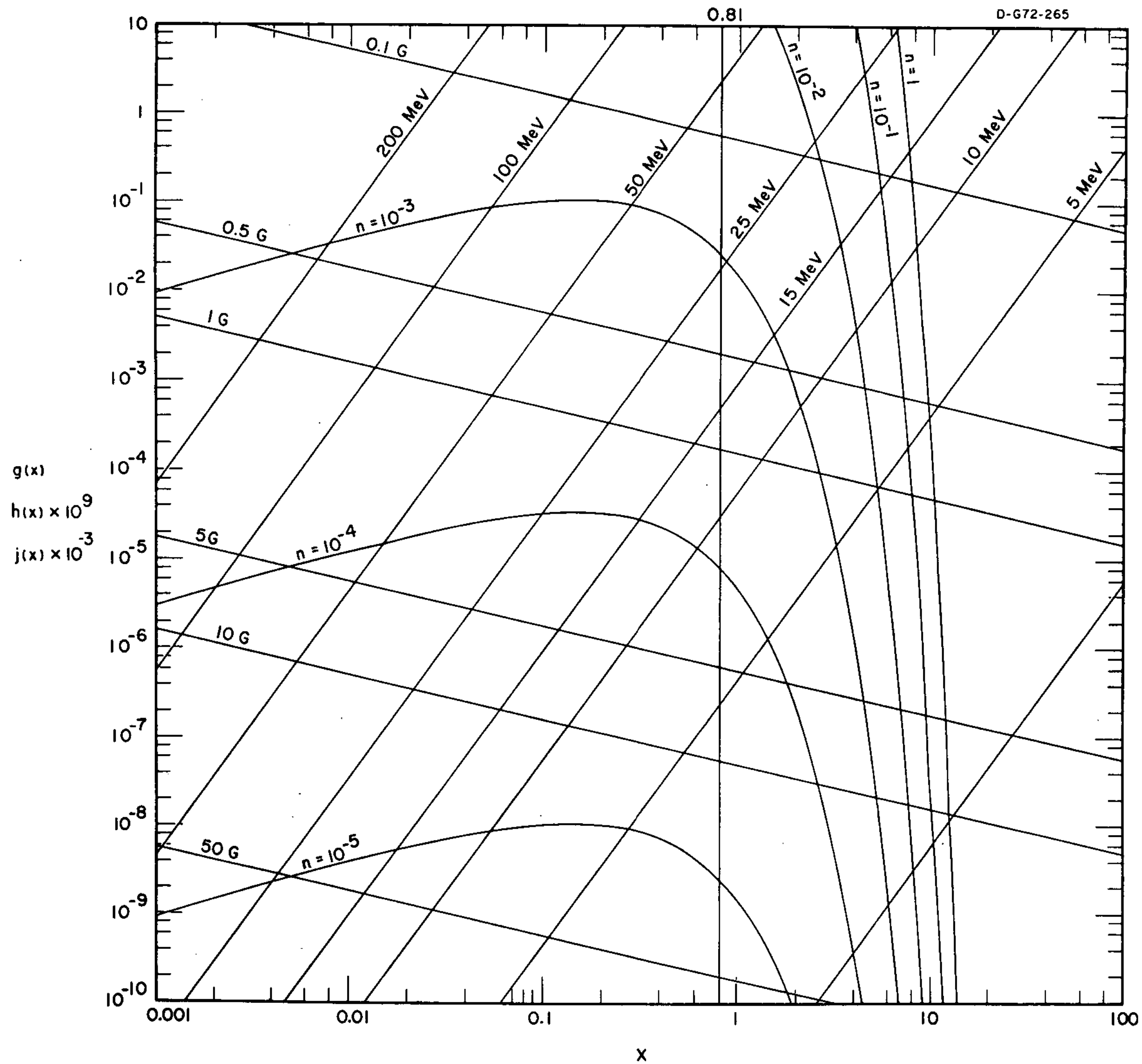

D-G72-265
0.81
0.1 G
0.5 G
1 G
5G
10 G
50 G
200 MeV
100 MeV
50 MeV
25 MeV
15 MeV
10 MeV
5 MeV
n = 10-3
n = 10-4
n = 10-5
n = 10-2
n = 10-1
n = 1
g(x)
h(x) × 10^9
j(x) × 10^-3
x
10
1
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
10^-8
10^-9
10^-10
0.001
0.01
0.1
1
10
100

Figure 5

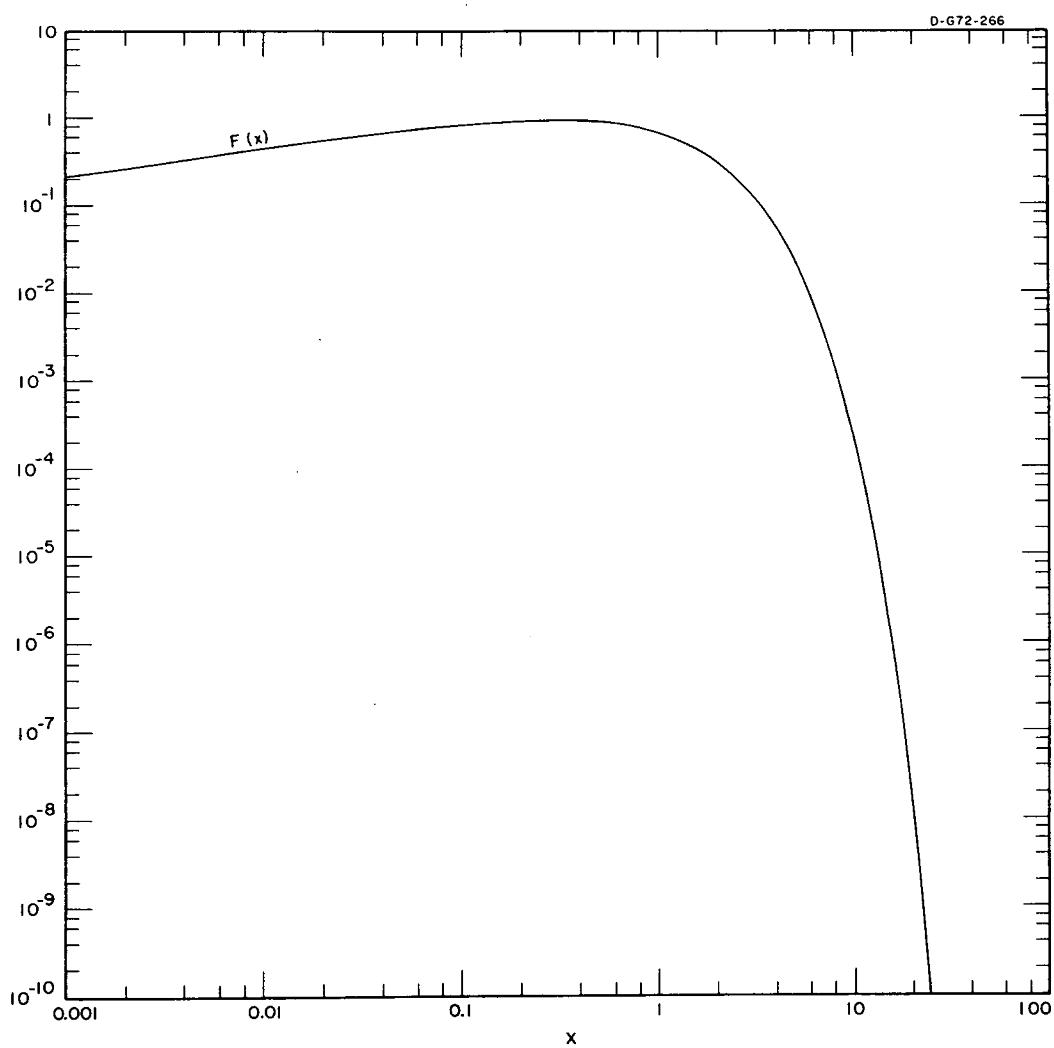
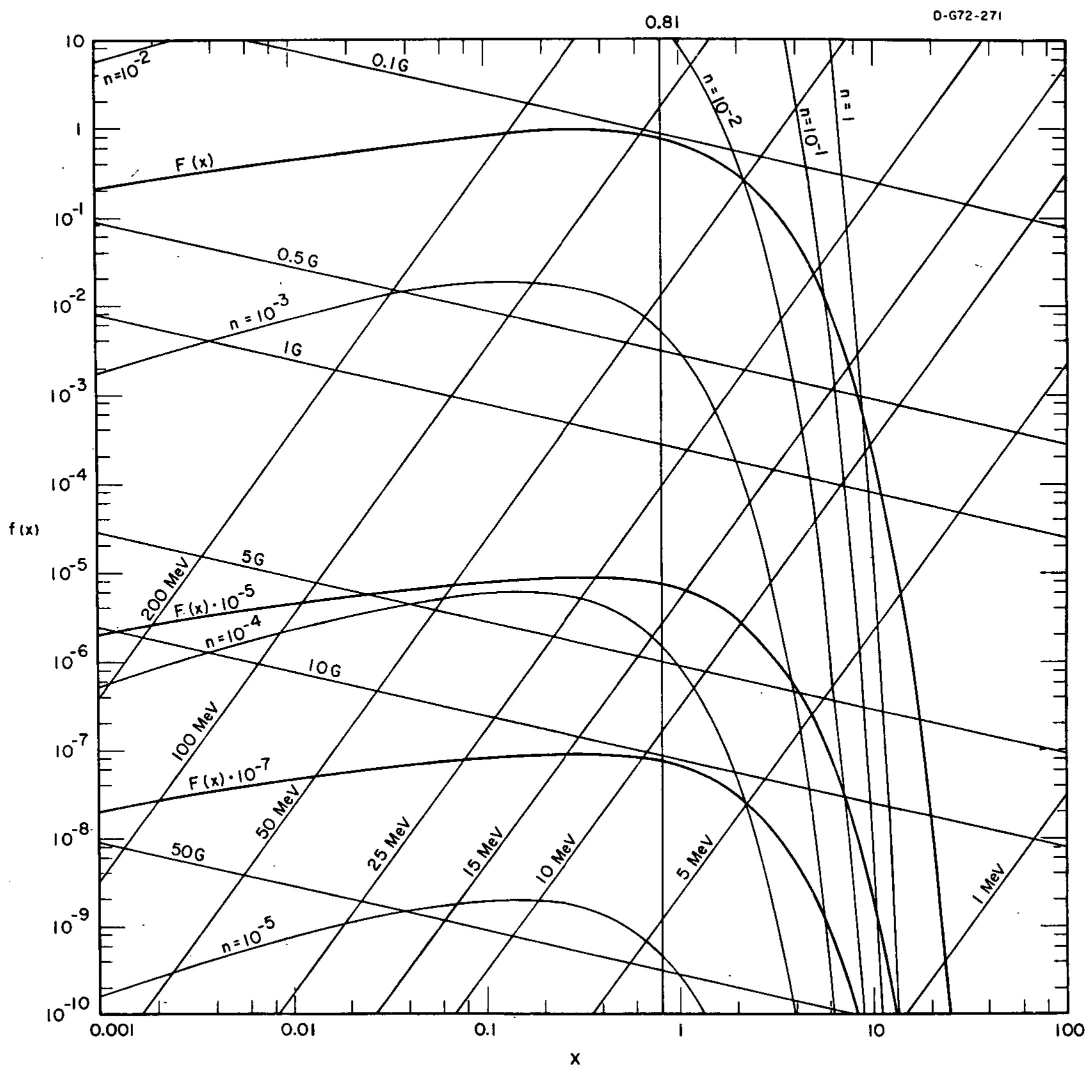

D-G72-266
F (x)
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
0.001
0.01
0.1
1
10
100
x

Figure 6



D-G72-271
0.81
n=10-2
0.1G
F(x)
n=10-2
n=10-1
n=1
0.5G
n=10-3
1G
5G
200 MeV
F(x)·10-5
n=10-4
10G
100 MeV
F(x)·10-7
50 MeV
50G
25 MeV
15 MeV
10 MeV
5 MeV
1 MeV
n=10-5
f(x)
10
1
10-1
10-2
10-3
10-4
10-5
10-6
10-7
10-8
10-9
10-10
0.001
0.01
0.1
1
10
100
x

Figure 7